Chapter 3
A Review of Microsimulation and Hybrid Agent-Based Approaches

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Abstract In this chapter we introduce an approach to individual based modelling of social and economic systems. Microsimulation models (MSM) appear similar to ABM through the representation of individual decision-making units, but there is a significant variation of emphasis between the two approaches. MSM are typically stochastic or rule-based, and with a strong applied policy focus. These characteristics are explored and elaborated through a number of examples. While MSM are often very rich in their representation of 'structures', ABM are usually better tuned to the analysis of 'behaviours'. We therefore argue that there is a strong logic to considering the MSM and ABM approaches as complementary and to begin a search for hybrids which might combine the best features of both approaches.

3.1 Introduction

Microsimulation models (MSMs) were introduced in the late 1950s by Guy Orcutt as a reaction to the failure of aggregate models to effectively represent the diversity of economic systems. Later developments have shown that the ambition of Orcutt's initial vision – the creation of a 'new type of economic system' (Orcutt 1957) – to be far from overstated. According to Gilbert and Troitzsch (2005), the distinguishing feature of MSMs is the desire to model interactions between the design and implementation of policies and individual decision making units (e.g. what is the effect of a changing tax regime on individual workers and their households). In contrast, cellular automata (CA) and agent-based models (ABMs) attempt to model the complexity of social systems with similar individual level representations, but

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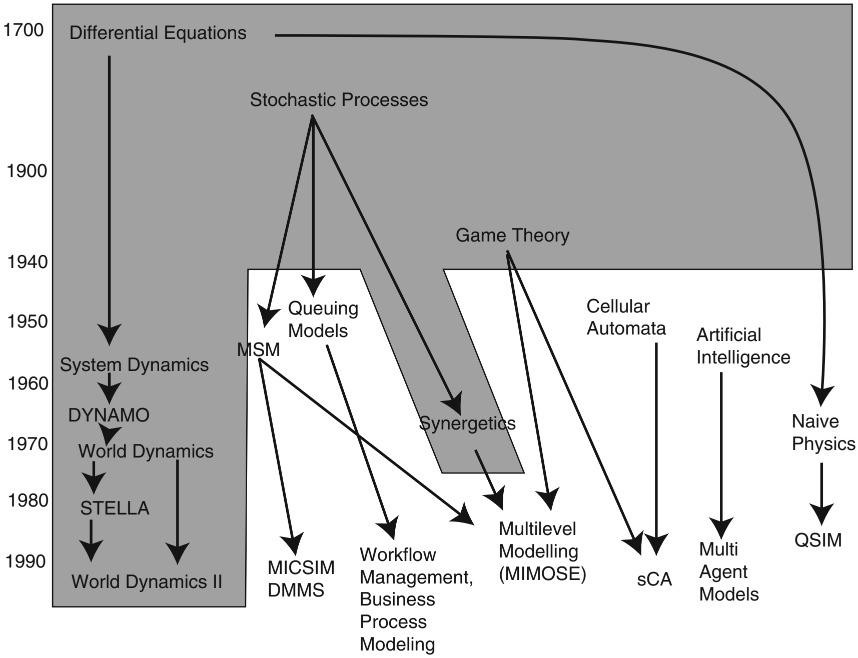

Fig. 3.1 Historical development of contemporary approaches (Source: Gilbert and Troitzsch 2005)

with a somewhat different emphasis. CA model social dynamics with a focus on the emergence of properties from local interactions while ABMs simulate more complex situations than the CA where the ‘agents’ control their own actions based on their perceptions of the environment. The relationship between these approaches is illustrated schematically in Fig. 3.1. An important feature here is the distinction between individual-based models and ‘differential equation models’, which focus on system level dynamics at the macro-scale. Figure 3.1 also seems to suggest a significant level of distinction between ‘stochastic processes’ (MSM), ‘cellular automata’ (CA), and ‘artificial intelligence’ (ABM).

The chapter is set out as follows. We first introduce microsimulation modelling as an approach to public policy analysis with a discussion of the most important characteristics and features of these models. The second half of the chapter deals with hybrid approaches through which we will explore the notion that some further fusion of these approaches could be desirable. Conclusions are drawn in the final section.

3.2 Microsimulation Models of Public Policy

Modern social science studies often require detailed information on the interactions between policy and the social-economic behaviours of people. MSMs capture such interactions through the simulation of distinctive behaviours and characteristics at the level of individual decision making units (Orcutt 1957). Advances in computing power and analytical techniques now allow great sophistication in the range of questions that MSMs can address.

A MSM works on the principle of creating small area microdata at a certain point in time and then generating future microdata from that basis (Ballas et al. 2005a). We start with a population of entities, set P, made up of individuals [P^1, P^2, …, P^n] where n is the number of individuals in the population sample. Each individual has a set of attributes, [a_1^t, a_2^t, … a_m^t], which describe the individual at time t. We therefore have an $n \times m$ array of person attributes. This array needs to be populated with reliable data or estimates (in the light of directly surveyed information, etc.). Then we update the population so that the baseline population [$P^1_{a_1^t a_2^t \ldots a_m^t}$, $P^2_{a_1^t a_2^t \ldots a_m^t}$, … $P^n_{a_1^t a_2^t \ldots a_m^t}$] changes to new sets with attributes/states at a point in time $t+1$, $t+2$, … and so on.

One of the most important advantages of MSM is that it enables us to examine the impact of policy changes on individual decision units, as it is based on unit records. This distinguishes MSM from the traditional mathematical models. Such models are often based on aggregated or averaged values and individual characteristics can often become blurred and even disappear in such models. MSM deals directly with social processes at the individual level, therefore it has been extensively used for various purposes in studies for which individual characteristics are important.

Although microsimulation modelling can be traced back to the pioneering work of Guy Orcutt (1957), the work of the Swedish geographer Torsten Hagerstrand was leading in a very similar direction at a similar time in the domain of migration and later innovation diffusion and location theory. Orcutt's research resulted in DYNASIM (Dynamic Simulation of Income Model) (Orcutt 1957; Orcutt et al. 1976), which has been used for a range of studies and inspired the development of many other MSMs. Among them is Steven Caldwell's (1998) CORSIM (Cornell Microsimulation Model), which models large scale government programs and is particularly strong in modelling the Social Security Programme. CORSIM constructs a database on the basis of a sample of 180,000 persons (70,000 families) from the 1960 US Census with demographic and economic attributes. CORSIM simulates changes of each individual unit (persons and families) on a yearly step. The resulting data are validated and aligned using the available external data before projections into the future.

CORSIM has a wide range of modules and therefore can be used extensively in different policy application domains. In 1995, CORSIM was selected by the Canadian government as a template for its own model development and the 'Canadianised' sister model was soon released as DYNACAN (Morrison 2003). In 1997, partly inspired by the Canadian strategy, the Swedish also selected CORSIM as the starting point of a new Swedish dynamic microsimulation model (SVERIGE), focused on exploring person-environment interactions (Rephann 1999).

3.3 Application Areas of Public Policy MSMs

In this section we aim to provide an introduction and overview to MSMs using examples from four domains in which the deployment of these models has been especially productive. The domains are tax and benefits, pensions, health and transport.

Of course, this range of domains is not entirely complete: for example, other examples can readily be found in anthropological systems, urban housing and local labour markets. It does however encompass the majority of work in microsimulation and can be used as a basis for understanding the nature of this research and its significance for individual-based modeling more generally. A synopsis of some important models is provided in Table 3.1.

Taxation and benefits is a core area building directly from Orcutt's original interest in economic systems. Tax-benefits models such as those shown in Table 3.1 aim to combine detailed representations of individual and household structures with well-defined rules about their financial entitlements. For example, if the annual (earned) income of an individual is £50 K, then the marginal rate of tax is 40%. Such models can then be used in a natural and conceptually straightforward way to examine the 'what if?' ramifications of changes in the rules (e.g. what happens if the marginal rate of taxation in the £50 K band is increased from 40% to 50%?). Because the representation of individual and household characteristics is so detailed in the MSM, this method is suitable for highly refined analysis which is often required here. Thus if housing benefits are assessed against, say, the income, occupation, and age of household heads, the composition of the family, and the tenure and physical size of the residence, then these characteristics and the associated benefit rates can all be represented relatively easily in the MSM.

Pension Microsimulations such as PRISM (Pension and Retirement Income Simulation Model) and PENSIM are typically used with a view to the future. In this way the National Insurance or other contributions of the existing workforce can be balanced against the specific entitlements of the retired population. Various policy responses to the impact of ageing populations in developed economies may be tested and evaluated. Similarly Health Microsimulations provide a powerful means to explore changes in the age and social composition of populations on the requirements for medical treatment and care. In addition to the national models outlined in Table 3.1, recent examples have begun to explore the implications of micro-demographic structure on morbidity and the spatial deployment of health care services such as diabetes (Smith et al. 2006, see also Smith, 2012), obesity (Edwards et al. 2011) and smoking-related illnesses (Tomintz et al. 2008). **Transport microsimulations** can be used for both transport policy assessment and simulation of a transport system or its components. The sheer breadth of these models is impressive, spanning all the way from microscopic simulation of individual vehicles to the representation of aggregate network conditions in a region or urban area.

The previous commentary, and the detail of Table 3.1, allows us to propose some useful conclusions about the technique of MSM. Firstly, flexible aggregation is a major strength of this approach. In the financial examples, we are primarily interested in the net effects of a rule e.g. how much benefit will the UK Exchequer derive from an increase in taxes, and what will be the distributional consequences of this change across social groups? The multiple application of rules across individual units is essentially a means to this end. Similarly in transport applications, the rules for individual vehicles may be quite detailed, but the ultimate objective is to say some-

Table 3.1 Comparison of static and dynamic MSM

Model name & domain	Origin	Description and example applications	Indicative reference(s)
(a) Tax-benefits			
TRIM (Transfer Income Model)	US	Simulates the major governmental tax, transfer, and health programs that affect the population; understand the potential outcomes of public policy changes such as welfare reform, tax reform, and national health care reform	Beebout and Bonina (1973)
POLIMOD	UK	Demonstrate how VAT, National Insurance Contributions and Local Taxes are calculated under different assumptions; entitlement to retirement pension and other non-means-tested social security benefits	Redmond et al. (1998)
STINMOD	Australia	Static micro-simulation model of the tax and transfer systems. The rules of government programs are applied to individuals and aggregated to calculate outcomes for income units, families, or households	Lambert et al. (1994)
ITEP	US	Calculates revenue yield and incidence of federal, state and local taxes by income group. It calculates revenue yield and proposed amendments to current law. To forecast future revenue and incidence the model relies on government or other widely respected economic projections	Ettlinger and O'Hare (1996)
EUROMOD	Europe	Tax-benefit model that covers 15 countries. It provides estimates of the distributional impact of changes to personal tax and transfer policy at either the national or the European Level	Sutherland (2001)
(b) Pensions			
PRISM	UK	Dynamic microsimulation of income from social security, earnings, assets, public and private occupational pensions and retirement savings plans	Kennell and Sheils (1990)
SfB3	Germany	Analyse pension reforms, the effect of shortening worker hours, distributional effects of education transfers, inter-personal redistribution in the state pension system	Galler and Wagner (1986)
PENSIM	UK	Simulate UK pensioners' incomes up to the year 2030 and to facilitate pension reform	Curry (1996)
DYNACAN	Canada	Projects the incidence, average levels and variation in private pensions into the future as a function of birth-year, age, and gender	Morrison (2003)

(continued)

Table 3.1 (continued)

Model name & domain	Origin	Description and example applications	Indicative reference(s)
(c) Health care			
PBS	Australia	Expenditure on pharmaceuticals by different types of households; resultant government outlays under the Pharmaceutical Benefits Scheme; and the remaining patient co-payment contributions	Walker et al. (1998)
LIFEMOD	UK	Model the lifetime impact of the welfare state through examination of health status over the life-course and implications for health care financing in the UK	Falkingham and Hills (1995), Propper (1995)
LIFEPATHS	Canada	A dynamic longitudinal microsimulation model of individuals and families which simulates the discrete events that together constitute an individual's life history	Wolfson and Rowe (1998)
(d) Transport			
DRACULA	UK	Simulate response of traffic to different network layouts and control strategies; measure network performance from outputs of the average travel time, speed, queue length, fuel consumption and pollutant emission	Liu et al. (1995)
PARAMICS	US	Microscopic simulation of a range of real world traffic and transportation problems handling scenarios ranging from a single intersection, to a congested freeway or the modelling of an entire city's traffic system	Laird et al. (1999)
VISSIM	Germany	Models traffic flow in urban areas as a discrete, stochastic, time step based microscopic model, with driver-vehicle-units as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements (lane changing)	PTV AG (2000)
AIMSUN	Spain	An evolutionary model of the transportation system which combines individual vehicle movements with network data such as traffic lights and detectors as well as road segments. Individual components are simulated in both continuous and discrete time-steps	Barceló et al. (1999)

(continued)

Table 3.1 (continued)

Model name & domain	Origin	Description and example applications	Indicative reference(s)
TRANSIMS	US	Predicts trips for individual households, residents and vehicles rather than for zonal aggregations of households. A regional microsimulation executes the generated trips on the transportation network, modelling the individual vehicle interactions and predicting the transportation system performance e.g. road speeds and motor vehicle emissions	TRANSIMS (1996)

thing about the underlying transport network and its configuration. This looks like a significant variation in emphasis from other approaches such as ABM where the interest in micro-level behaviours 'for their own sake' is much more fundamental.

It is clear that the range of applications for MSM is hugely varied in relation to both geography and substantive problem contexts. One outstanding feature which is common to all of the models in Table 3.1 is their policy-relevance. A recurring theme is the idea of 'what if?' simulations in which the impact of new policy rules on the whole system, or individual components and sub-groups can be assessed. Alternatively, the rules may stay relatively constant but the underlying conditions are changing fast, for example in the case of demographic changes which can have profound implications for taxation, pensions, health care and transport systems.

Finally, while many of the applications are described as 'dynamic' it is necessary to retain a healthy degree of skepticism as to the precision of this term. Often dynamics in these models will be little more than a cross-sectional or comparative static assessment of some globally assumed shift in the composition of the population. The incorporation of pure dynamics in which the individuals in the population actually evolve through time, whether through stochastic rules or more complex behavioural model processes is much more demanding and unusual. This feature is sufficiently important to demand further expansion in the next section.

3.4 Dynamic Microsimulation

Generally speaking, static MSMs do not have direct interaction of microanalytic units within the context of the model during the time period simulated. Static models normally are either deterministic or stochastic. In a static microsimulation, change of the demographic structure in the model is performed by static ageing techniques. Typically such techniques take a large representative sample with detailed information and apply modified laws to it to generate the synthetic demographic and economic characteristics expected in the future year. Simulations can estimate the impact of a change in the future year As the change of the demographic structure of the modelled population is performed by reweighting the age class according to external information, it is focused on what consequences of external information brings to the population and therefore it does not model the changes in population itself. A typical “What-if” Static MSM scenario would be: if there had been no poll tax in 1991, which communities would have benefited most and which would have had to have paid more tax in other forms? (Ballas et al. 2005b; Gilbert and Troitzsch 2005; Citro and Hanushek 1991)

Most tax-benefit MSMs are static. Examples of static microsimulations include models such as TRIM (Beebout and Bonina 1973), POLIMOD (Redmond et al. 1998), STINMOD (Lambert et al. 1994) and EUROMOD (Sutherland 2001). Descriptions of such models can be found in the previous section.

Dynamic MSM can be considered as a technique where entities change their characteristics as a result of endogenous factors within the model. Various degrees of direct interaction between micro population units can be found in dynamic MSMs. Such interaction typically includes processes such as birth and marriage etc. Dynamic microanalytic models rely on an accurate knowledge of the individuals and the dynamics of such interactions. In a dynamic MSM, the updating of the demographic structure is performed by ageing the modelled population individually (by asking “yes or no” questions on birth, death, marriage etc.) with transition probabilities according to life tables and/or exogenous time series. Thus the changes in the population itself are modelled and the simulation in 1 year may affect an individual unit’s characteristics in the subsequent year. A typical future-oriented “what if” Dynamic MSM Scenario would be: if the current government had raised income taxes in 1997, what would the redistributive effects have been between different socio-economic groups and between central cities and their suburbs by 2011? (Birkin et al. 1996; Ballas et al. 2005b; Gilbert and Troitzsch 2005; O’Donoghue 2001).

A variety of models have been developed to explore the distributional consequences of demographic change, such as ageing, social mobility and labour market transitions. Thus the **DYNASIM** model ages individual and family characteristics by year, simulating demographic events as births, deaths, marriages and divorces and economic events as labour force participation, earnings, hours of work, disability onset, and retirement. It models a wide range of topics, including Social Security coverage and benefits, pension coverage and participation, benefit payments and pension assets, as well as home and financial assets, health status and living arrangements etc. (Favreault and Smith 2004).

In a similar way **DYNAMOD** (Harding 2002) uses discrete event simulation to age a 1% sample from the Australian census (about 160,000 individuals) on a monthly basis for up to about 60 years. Assets and superannuation have been adding to DYNAMOD to facilitate the research of the likely future retirement incomes of Australians.

SAGEMOD (Zaidi 2004) is a dynamic demographic/tax model which not only estimates incomes but also estimates a random-effects cross-sectional wage equation which included some individual wage history data with the error components. The impact of other labour market states (unemployed, inactive, student) in previous years has been investigated on the earnings of currently employed individuals.

Static and dynamic MSM each have their own strengths. Static models are regarded as more effective at times for specific short run projection purposes because of their greater simplicity and the often lower costs associated with building such models and obtaining computer generated model solutions. Another advantage of static models is that they have very detailed programme simulations. From the computational viewpoint, static MSMs demand less computing resource.

However, dynamic models feature more detailed and realistic population ageing. There is general acceptance that dynamic models provide a more realistic representation of micro population unit behaviour. Dynamic models are also viewed as better at producing realistic long-term estimates, which account for interim changes in economic and demographic trends (O'Donoghue 2001). Due to the interactions/interdependencies of the updating, one limitation is that dynamic MSMs are computationally demanding, even for high-speed modern machines (Ballas et al. 2005b; Gilbert and Troitzsch 2005; Citro and Hanushek 1991; McDonald, et al. 2006).

3.5 Spatial MSM

Spatial MSM is a special type of MSM that simulates virtual populations in given geographical areas (Ballas et al. 2005b). In a spatial MSM, local contexts can be taken into account when studying the characteristics of these populations. Such MSMs are concerned with the creation of large-scale datasets estimating the attributes of individuals within the study area and are used to analyse policy impacts on these microunits (Birkin and Clarke 1995; Clarke 1996). Spatial microsimulation models therefore have advantages over other microsimulation models in exploration of spatial relationships and analysis of the spatial implications of policy scenarios. A spatial MSM can be either static or dynamic.

Spatial MSM was first studied by Hägerstrand (1985) since the 1950s by first introducing the spatial and temporal dimensions into social studies. Wilson (1967), Clarke (1996) and Birkin and Clarke (1995) extended the theoretical framework over the years. Various spatial microsimulations have been developed, including both static and dynamic microsimulations. They allow data from various sources to be linked and patterns to be explored at different spatial scales with re-aggregation or disaggregation of the data. Furthermore they allow updating and projecting, which is of particular importance in forecasting future patterns (Clarke 1996; Ballas and Clarke 2001).

Examples of such models include: **SVERIGE** in Sweden (Rephann 1999). This dynamic population model is designed to study human eco-dynamics (the impact of human cultural and economic systems on the environment). Its main distinguishing characteristic is that it simulates spatial location and mobility of every individual in the data. The model took the CORSIM model framework as a starting point, adapting behavioural modules to be Swedish specific. The migration module attempts to model locational transitions to an accuracy of 100 m.

SimBritain (Ballas et al. 2005c) is a dynamic simulation attempting to model the British population at different geographical scales up to the year 2021. Datasets used in this model are the 1991 UK Census Small Area Statistics (SAS) data and the British Household Panel Survey (BHPS). Microdata for all wards in Britain have been generated through re-weighting the original BHPS data. Previous census data from 1971, 1981 and 1991 (SAS) have been used for projections of a set of small area statistics. Using these three time points, a trend curve was produced allowing tables to be predicted up to 2021.

SMILE in Ireland (Ballas et al. 2005a) is a dynamic spatial microsimulation model designed to analyse the impact of policy change and economic development on rural areas in Ireland. The core model of SMILE is a demographic model. It simulates the basic components of population change, fertility, mortality and internal migration and projects population change at the sub-county level.

HYDRA in the UK (Birkin et al. 2005) is a GRID enabled decision making support system for health service provision. Microsimulation can be run using different parameter sets by the user to find out the optimised location of services for specific queries (further details can be found in Wu and Birkin, 2012).

3.6 Towards a Hybrid Modelling Approach

Over the years, MSMs have been proved to be successful in modelling social systems, especially in facilitating public policy making and development. Large scale MSMs enable us to explore the interaction between policy changes and narrowly defined ranges of individuals or demographic groups, yet retain the heterogeneity in the population as revealed in the large household surveys. The capability of MSMs to replicate complex policy structures also allows us to forecast the outcomes of policy changes and 'what if' scenarios. However, there are also criticisms levelled at MSMs which include:

- MSMs require large datasets with high quality;
- Microsimulation model developments are normally computing intensive;
- Large scale microsimulations can take a long time and considerable effort to accomplish;
- Microsimulation only models one-direction interactions: the impact of the policy on the individuals, but not the impact of individuals on the policy;
- Microsimulation models are less strong in behavioural modelling; and
- It is difficult to validate MSMs (Krupp 1986; Williamson 1999; Citro and Hanushek 1991; O'Donoghue 2001; Gilbert and Troitzsch 2005).

Some of these limitations are better handed by individual-based models such as cellular automata (CA) and agent-based models (ABMs). More details about both modelling types can be found in Iltanen (2012) and Crooks and Heppenstall (2012). Although MSMs, CA and ABMs each have a different focus, they all model the studied system at individual levels, and there is some common ground among the three approaches. Firstly, all three approaches are simulations based on the global consequences of local interactions of members of a population. Unlike the aggregated models that often overlook the details at a more refined level, they provide a more effective and natural way to handle individual behaviours. Secondly these three approaches all track the characteristics of each individual through time, in contrast to traditional modelling techniques where the characteristics of the population are averaged together. Finally the emergence of global phenomena through local interactions in all IBMs (individual-based models) offers more than changes that are simulated on the basis of average data for the whole population as in traditional models.

With the advance in computing, the first three limitations have been improved greatly and new technologies such as ABM can provide the capability for behaviour modelling and allow us to study the interaction at both macro and micro levels, as well as interactions in both directions. However, despite the usefulness of ABM as described in the previous discussion, being a relatively new technology, it sometimes lacks more refined and well-established theories and concepts (Gilbert and Troitzsch 2005; Conte et al. 1998). ABM is also known as hard to validate. Many applications of agent systems to public or social policy domains involve the development of alternative scenarios to facilitate decision-making. However, there is no formal theory of scenarios and scenario analysis that tell us how to construct scenarios, how many scenarios to construct and how to reason between and across their outcomes. Developing formal theories of scenarios and rigorous methods of performance assessment for ABM will require collaboration between computer scientists, philosophers and decision theorists, as well as the domain experts to which these systems are applied.

Despite the work that remains to be done, agent-based social simulation can provide insight into the structure and effects of policies and norms and can assist in understanding and modifying interaction patterns where appropriate and possible (Luck et al. 2003).

To address the limitations of ABMs and MSMs as individual approaches, we suggest further development of a hybrid modelling approach that integrates the strengths of both approaches together. The main reasons for the proposal of such a hybrid approach include:

- MSM and ABM complement each other;
- Geography provides a bridge to link MSMs and ABMs;
- Previous attempts of hybrid approaches have resulted in fruitful outcomes;
- A hybrid approach may provide a new angle to view classical problems.

The following sections review various relevant hybrid modelling approaches.

3.6.1 ABM and MSM

It is generally agreed that MSMs provide important and effective tools for modelling in social science. Recent advances have helped to mitigate some of the major weaknesses of MSM as outlined above at the start of Sect. 3.6 (Holm et al. 1996).

In particular, high quality data is now much more widely available, and large scale process intensive simulations are better supported by the computational abilities of contemporary hardware. However the robustness of the behavioural basis to MSMs can still be questioned. According to Davidsson (2001) even dynamic MSMs fail to match up to ABM to the extent that such models do not justify the behaviours of each individual in terms of individual preferences, decisions, plans, etc. Furthermore, the interactions between individuals are not modelled in the simulation. Thus ABM is "well suited for the simulation of situations where there are a large number of heterogeneous individuals who may behave somewhat differently and is therefore an ideal simulation method for the social sciences" (Davidsson, 2001, p. 145). This view is endorsed by Jennings (2000) who highlights the advantage of ABM in modelling the intelligent behaviour of individuals by itself or in society. Interestingly, in relation to debates about processing capacity, Jennings also notes the potential of ABM for improving efficiency by distributing the control of the computation to multiple simpler units evolving through their interactions.

In addition to their capabilities for representing social behavior, the capacity of ABM to bring together diverse perspectives has been highlighted by Axelrod (2005). Social science is multi-disciplinary and social models often need to involve different disciplines. For instance a sustainability model would involve environmental, social, economic, and other disciplinary considerations. Such multidisciplinary tools are particularly valuable when the underlying mathematics are intractable. Taking the evolution of genes as an example, Axelrod pointed out that agent-based modeling could easily simulate the evolutionary effects of genes where application of mathematical equations is difficult. In this way, ABM can begin to reveal elements of the harmony between disciplines. For instance, Axelrod found that an agent-based model about military alignments could successfully predict strategic alignments of computer companies.

From an interdisciplinary perspective, David et al. (2004) also point out that ABM based social simulation originates in the intersection of the social and the computer sciences and this interdisciplinary character has encouraged collaborations from scientific fields. They also suggest that the wide interpretative scope of the theory of agents and the advances in computer capability have enlarged the communicative and interpretative room for ABM to interchange between different scientific fields and model interdisciplinary complex systems.

Nevertheless it is more constructive to view the relationship of ABM to MSM as one of complementarity rather than supremacy. One reason for this is the relative recency of the ABM paradigm, which can therefore profit from the more refined and well-established theories, concepts and models of social organizations and institutions developed within the social sciences (Conte et al. 1998). This rationale stresses that computational modeling is not just an applied tool, but a means for the production, testing and refinement of social theories. Such an eclectic view also allows for the development of more refined theories about social agents. For example, moving away from static and unsophisticated views of individual actors which overemphasise either rationality or simple social learning as a basis of behaviour. Hence we suggest that the fusion of microsimulation and agent perspectives is potentially an ideal combination in the study of both social structures and social behaviours.

3.6.2 GI Science and ABM

Torrens and Benenson (2005) proposed a new paradigm for integrating GIS and agent based simulation called Geographic Automata Systems (GAS). This system takes advantage of the formalism of automata theory and GIS to unite cellular automata and multi-agent systems techniques and provides a spatial approach to bottom-up modelling of complex geographic systems that are comprised of infrastructure and human objects. In this framework, geographic phenomena as a whole are considered as the outcomes of the collective dynamics of multiple animate and inanimate geographic automata. Geography serves as the binding force in merging CA and ABM (which are popularly confused in the geographic literature). Therefore automata become uniquely geographical, fusing CA and ABM but extending the concept to incorporate notions from GIS and Spatial Analysis.

Murphy (1995) believes that the evolution of GIS as a decision support system relies on improvements in technology, the creation of new analysis tools, and increased understanding of the interaction between decision support tools and the decision maker. He also points out that particularly fruitful areas may come from the use of artificial intelligence approaches for alternate representation of decision domains and knowledge. He thinks cooperation between the disciplines will be particularly beneficial in areas such as data quality, uncertainty representation and issues related to the management and sharing of large time-reliant and source-dependent data. Thus, a rewarding exchange may be possible between GI Science and decision support system research streams relating to the management, representation, and interpretation of complex multi-dimensional knowledge.

Gonçalves et al. (2004) suggest that GIS and ABM address space in different perspectives: GIS models geographic space and ABM models the behaviour of intelligent agents within geographic space. Gonçalves et al. propose a conceptual framework for integrating these different perspectives in the context of modelling and simulation of complex dynamic systems. They suggest that GIS enables the definition of a geographic region to be related with the phenomena in that region, but GIS do not seem to be appropriate to study dynamic phenomena in an area. Most ABM tools that use geographic information are not coupled with GIS. However, the simulation of the human behaviour with mobility in geographic space and intelligent behaviour has increased in the recent decades, which has led to a special interest in the integration of agent based models (mainly ABM) and GIS.

The authors proposed that in the hybrid model, ABM can be used to model the intelligent behaviour of entities, e.g. behaviour of people, animals, enterprises, etc., while GIS can be used to model geographic space. Intelligent agents move and reason within this environment. The authors also point out that GIS are already extensively used by people from the natural sciences, civil engineering, territory management authorities, urban planning, etc. Therefore there is no point not to give them what they already know plus the agents.

3.6.3 Unification of MSM, ABM and GI Science

As discussed in the previous section, attempts to bring MSM and ABM together (Caldwell et al. 1998; Rephann 1999) or ABM and GI Science together (Torrens and Benenson 2005) or MSM and GI Science together (Ballas et al. 2005b; Holm et al. 1996) have succeeded.

Given the characteristics of the agent based technology and geographical importance in social policies, researchers including Boman and Holm (2004) have promoted the study of social systems using a combination of different paradigms of MSM, ABM and 'time geography'. Boman and Holm argue that time geography provides a perspective to help unify the two paradigms of ABM as developed within computer science and MSM as developed within the social sciences. Time and space have important impacts on human activities in any social system. The authors suggest that time geography provides an alternative perspective on agents and collectives since it emphasises the importance of concurrent micro-level representation of agents and their relations to other agents. Time geography can also introduce a conceptual framework for analysing social micro-level interaction in time-space in MSM and ABM.

Boman and Holm (2004) attempt to unite the two paradigms through defining them and reasoning about the central concepts of each of them. They found that all three methodologies emphasise individual representation and computational solution. However many MSMs only apply a fairly aggregated and disconnected representation of individual behaviour, while ABM can provide the capacity to model individual adaptive behaviours and emergence of such behaviours. Their argument for a MSM-time geographic approach is that aggregation prior to analysis and modelling of trajectories over the state space of individuals with several attributes distorts not only individual but also aggregate results. Individual trajectory interactions and constraints need to be modelled individually to reflect the whole picture. On the other hand, MSM are developed with high estimation and validation ambitions, close to observables that facilitate empirical tests.

Therefore, developments based on a synthesis of the three paradigms can offer great potential in the advance of systems analysis methodology. Boman and Holm (2004) believe it gives a new angle to classical problems where we need to:

1. achieve consistency with the world outside a defined core system boundary;
2. simultaneously represent processes on different spatial and temporal scales;
3. enable agents to concurrently obey internal and external rules, and
4. integrate observable and postulated behaviour while preserving achievability of endogenous emergence (Boman and Holm, 2004: p. 108).

The potential benefits to the integration of MSM and ABM can be seen in relation to each of the application domains which were considered earlier. Whereas financial MSMs look at the stochastic consequences of changing rules, an agent perspective will perhaps provide some insight about new behaviours in response to a change in the background conditions. For example, changing the rules on housing benefits to unmarried partners might not just result in a change in payments, but could lead to fundamental shifts in patterns of marriage, cohabitation and family formation. A similar point could be made in relation to pension microsimulations. So if the retirement age is raised from 65 to 70, then the adjustment is probably much more complex than everyone simply agreeing to work 5 years longer. While demographic ageing is a major driver of changing health needs, the ability to provide care will be equally important. As the pressure on formal care increases then the value of informal care will also rise disproportionately, but this balance will presumably change as dependency rates become higher. Some study of the behavior of agents within social networks through which (informal) care is provided could be a fundamental component of a more effective model. Lastly, in relation to transport some of the boundaries here are already quite blurred to the extent that many systems already bridge all the way from the driving patterns of individual vehicles to strategic decisions about road networks and infrastructure provision (see the examples in Table 3.1). To the extent that individual behaviour is richly accommodated within these models then they start to look like ABM anyway, especially if individual interactions are accommodated. On the other hand, if individuals are characterized as 'agents' but their activity patterns are very predictable and well-defined then maybe they are not so different to MSM after all.

3.7 Conclusions

This review has suggested that MSM provides a powerful approach in modelling social systems and has a particular importance in public policy modelling studies. It has been widely used in a range of application domains, and major developments of MSMs have been experienced all over the world in the past few decades.

Although MSM has limitations such as requirements for both data and computational capacity, recent advances have rendered these issues as less significant. More importantly, new technologies such as ABM are naturally complementary for traditional MSMs. One advantage of using ABM is that it allows us to model these systems not only using traditional maths and statistics, but also using behavioural information, for which MSM has been criticised. The flexibility of ABM can also help us to achieve consistency outside a defined core system boundary. The usage of ABM enables us to generate the emergence of global complexity from relatively simple local actions and hence may also further reduce the computing requirements imposed by long-range interactions in a social system.

Geography has an important impact on human activities and therefore it is important to model the social system with its local context. The geography also provides a bridge to link MSM and ABM together, and the hybrid approach may provide an alternative way to study social problems.

As previously discussed, the success of hybrid approaches in modelling and simulating social systems provides the basis for the unification of MSM and ABM. A hybrid approach may offer a great potential for substantial advances in modelling social systems.

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